ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

PROJECT NO. 2 - OPERATIONS AT HIGH TEMPERATURES

First Partial Report

On

Sub-Project No. 2-22, Determination of the Amount of Heat Transmitted to the Fighting Compartment of Tanks Under Field Conditions

Project No. 2-22

17 August 1943

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1. PROJECT: No. 2 - Operations at High Temperatures. First Partial Report on: Sub-Project No. 2-22, Determination of the Amount of Heat Transmitted to the Fighting Compartment of Tanks Under Field Conditions.

a. Authority - Letter Commanding General, Headquarters Armored Force, Fort Knox, Kentucky, 400.112/6 GNOHD, dated September 24, 1942.

b. Purpose - To determine the adequacy, from the standpoint of heat dissipation by the crew members, of the limited rate of ventilation which is provided through the gas canister in a gas-protected tank.

2. DISCUSSION:

a. Owing to the space requirements of the gas canister and other equipment required in the conversion of the ventilating system in M4 tanks to the positive-pressure type for gas-protection, the rate of ventilation through the canister is limited. At the present time it appears that a rate of no more than 175 cfm is possible.

b. This limited rate of ventilation is in sharp contrast to the quantity of air flowing through the crew compartment of the standard M4 tank (buttoned-up) which varies from 500 cfm with engine idling to more than 2000 cfm when the engine is operating at cruising speed. Because of the great reduction in ventilation, the question is raised as to whether or not the air flow is sufficient to absorb and remove the heat released inside the tank and the moisture given off by the crew during the periods of continuous operation with the tank buttoned-up.

c. Data with respect to the adequacy of the reduced ventilation from the standpoint of heat and moisture removal were obtained during actual driving tests on the range with a full crew in the tank. Details of the test procedure and results are presented in the appendix.

3. CONCLUSIONS:

a. A rate of ventilation of 175 cfm in the crew compartment of the experimental M4A3 tank (without special insulation of the transmission and final drive housing) does not remove the heat or the moisture at sufficient rates to maintain a tolerable atmospheric environment within the tank during a continuous period of buttoned-up driving, even on a moderately warm summer day.

b. If the anticipated combat conditions with respect to enemy use of gas are such that the gas-protected tank must operate buttoned-up and be continuously prepared for attack by chemical warfare agents for prolonged periods in moderately warm areas (where, for example, the temperature and humidity exceed 85° F. and 60 percent R.H., respectively) then additional facilities for crew cooling will be required.

4. RECOMMENDATION:

That this report be distributed to the agencies concerned with the development of gas-protection of tanks.

Prepared by:

Lt. Col. Theodore F. Hatch, SnC
Lt. Robert H. Walpole, SnC
Lt. Glasselle S. Lawson, Inf.

APPROVED Willard Machle
WILLARD MACHLE
Colonel, Medical Corps
Commanding

3 Incls.

#1 - Appendix
#2 - Tables 1 thru 3
#3 - Figures 1 thru 6

APPENDIX

In the standard series M4 Medium Tank the rate of ventilation through the crew compartment with the tank buttoned-up varies from 500 cfm at idling engine speed* up to rates in excess of 2000 cfm with the engine operating at cruising speed. In contrast to this, in the experimental gas-protected tank (M4A3) described in a recent report from the Laboratory**, a rate of ventilation of only 175 cfm is provided through the gas canister. Owing to the limited space available in the tank for the canister and other parts of the ventilation equipment it does not appear that a higher rate of ventilation during gas protection can be anticipated.

Field observations and Laboratory measurements have shown that even with the high rate of ventilation provided in the standard tank, the solar heat absorbed and the heat given off by the transmission and final drive and the moisture released by the crew are sufficient to raise the temperature and moisture content of the air within the tank an appreciable amount. In view of this fact question may properly be raised as to the adequacy of the limited ventilation which would be available through the canister in a gas-protected tank, from the standpoint of heat and moisture removal.

TEST PROCEDURE

Data collected under summer climatic conditions at Fort Knox are reported herewith. The tests consisted in operating the tank on the highway and cross-country in accordance with the standard schedule shown in Table 1. This schedule, which may be referred to as a "standard tank day", is not necessarily representative of a typical day under actual field conditions but contains the elements of such a day. In each test the tank was fully manned and at intervals throughout the day temperature readings were taken in the tank according to the schedule in Table 2. Observations on the crew included initial and final body weights and temperatures, the body temperature at the end of the 1.5 hours of buttoned-up driving in the afternoon and a record of the water consumption and excretion during the day. Tests were run on the experimental tank on 3 different days, one a moderately cool day with little sun, the second an average summer day with variable sunshine and the third a day of moderately high temperature with substantially continuous sunshine. For comparative purposes, a similar test was carried out with a standard tank, also on a moderately warm day with fairly continuous sunshine. At half hour intervals during each day of test the following measurements were taken at the Laboratory central weather station: (1) dry bulb

* Approximately 500 cfm in the M4A2, M4A3 and M4A4; 1000 cfm in the M4A1.
** Project No. 3. Toxic Gases in Armored Vehicles. Second Partial Report on Sub-Project No. 3-9 - Determination of Ventilation Requirements for Gas-Proofing Tanks of the M4 Series. 23 June 1943.

Encl #1

temperature in the shade, (2) wet bulb temperature in the shade, (3) wind velocity, (4) solar radiation on a horizontal surface. The climatic data were taken at a point approximately 3 miles from the driving range but simultaneous check readings of temperature and humidity on the range revealed no differences. Interior surface temperatures in the tank were determined by means of thermocouples attached to the metal under conveniently located nuts. Dry bulb temperatures at the various crew positions were measured by hanging thermometers and the moisture content of the air in the bow and turret was determined by means of an aspirating psychrometer which had been checked against the fan-operated psychrometer at the control station.

RESULTS

The records of temperature and humidity within the experimental tank and in the standard vehicle are shown in Figures 1 to 4. The climatic data for the four days are also shown on the graphs.

a. Performance of experimental pressure tank compared with standard tank. Figures 1 and 2 give the surface and air temperatures and the humidity inside the standard and experimental tanks respectively, under closely comparable outside conditions. Although the tests were run on two different days, it will be observed that the outside dry and wet bulb temperatures and the solar radiation values were practically the same. The wind velocity was somewhat lower in test 2 with the pressure tank. Atmospheric conditions inside the two tanks, however, were strikingly different. The dry bulb temperatures did not differ greatly but there was a general elevation of the wet bulb temperatures in the experimental tank as compared with the standard vehicle resulting from the increased moisture content of the air. This is shown clearly in Table 3 which gives the increase in moisture content of the tank air over outside air for both vehicles. At the end of the morning and afternoon periods of operation with the tanks buttoned-up, the moisture content of the air in the standard tank averaged approximately 30 percent in excess of that in the outside air. In the pressure tank, on the other hand, the excess moisture content averaged 62 percent at the end of the morning period and 113 percent in the afternoon. These striking differences resulted from the fact that there was insufficient rate of air flow through the gas-protected vehicle to absorb the moisture given off by the crew members. As a result, rapid deterioration of the atmosphere from the standpoint of crew comfort occurred. Further indication of the effect of the limited ventilation is seen in Figure 5 which shows the increase in effective temperatures* in the two

* The effective temperature scale combines in one reading the effects of temperature, humidity and air movement upon heat loss from the human body. An environment having a dry bulb temperature of 105° and a wet bulb of 85° F and zero air velocity, for example, has an effective temperature of 90° F. This is equivalent to a saturated atmosphere of 90°F and zero velocity. It is also equal to an atmosphere having a dry bulb temperature of 100°, wet bulb temperature of 90°, and an air velocity of 200 fpm.

Sub 1/

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* The effective temperature scale combines in one reading the effects of temperature, humidity and air movement upon heat loss from the human body. An environment having a dry bulb temperature of 105° and a wet bulb of 55° F and zero air velocity, for example, has an effective temperature of 90° F. This is equivalent to a saturated atmosphere of 90°F and zero velocity. It is also equal to an atmosphere having a dry bulb temperature of 149°, wet bulb temperature of 90°, and an air velocity of 500 fpm.

vehicles in comparison with the effective temperature level for the outside air, assuming in the latter case the same air velocity as inside the tanks. Effective temperatures for the outside air were substantially the same during the two tests. Inside the standard tank the effective temperature did not exceed 90°, whereas within the pressure tank and particularly in the bow, the effective temperature throughout most of the day was in excess of 90°, and at the end of the afternoon period of buttoned-up operation reached a level of 96.5°. There was a steady rise in effective temperature during the morning and afternoon periods of operation which indicates that even more serious deterioration of the inside atmosphere would have occurred had the period of buttoned-up operation been continued. It should be noted that during these tests the temperature of the transmission in the pressure tank ran uniformly below the transmission temperature in the standard vehicle with a corresponding lesser radiation heat load which is not included in the effective temperature scale. This improvement resulted, no doubt, from the relocation of the transmission oil cooler on the engine compartment deck where it was more effectively ventilated. Bow and turret skin temperatures did not differ markedly in the two tanks.

Rapid deterioration of physiological function occurs when the effective temperature exceeds 90° and when it approaches body temperature (98.8), this deterioration will lead to complete collapse if exposure is prolonged. At 1430 hours, in the case of the experimental pressure tank, the body temperature of the driver and assistant driver had increased over 3.0°F. In the standard tank, on the other hand, the increase in body temperature was less than 1.0°F. The total water loss throughout the day amounted to 6.3 pounds per man (9.35 pounds for driver) in the pressure tank, and 4.1 pounds in the standard vehicle (6.3 pounds for driver). At the end of the afternoon period of buttoned-up operation, the crew in the pressure tank showed definite signs of heat exhaustion.

b. Atmospheric conditions inside gas-proof tank in relation to outside thermal conditions. The atmospheric conditions within the gas-protected tank were found to vary with outside conditions, as would be expected. In figures 2, 3 and 4, one notes progressive improvement in the thermal conditions within the vehicle as the outside temperature and amount of solar radiation decreased. Figure 6 shows the effective temperatures in the bow during the three days together with the average outside climatic conditions. In contrast to the serious deterioration in the tank atmosphere which was observed on a moderately warm day with continuous sunshine (Fig. 2), operation of the gas-protected tank on a cool day with low solar radiation did not produce unacceptable interior conditions (Fig. 4). The effective temperature reached a maximum of 87.5° and there was no significant rise in body temperature. The total water loss throughout the day averaged 3.5 pounds per man. Attention should be called, however, to the fact that there was a significant rise in moisture content of the tank air at the end of the morning and afternoon periods of buttoned-up operation, the average increases being 50% and 70% respectively. This again attests to the limited capacity of the quantity of air flowing through the tank to take up moisture.

On the intermediate day with irregular sunshine and average temperature (Fig. 3), effective temperatures in excess of 90° were encountered during the afternoon period of buttoned-up operations only, with an increase in moisture content over outside air of 75%. The total water loss throughout the day was 7.2 pounds per man* and the average rise in body temperature at 1430 hours was 1.0° F.

CONCLUSIONS

a. It is evident from the findings of these tests that a rate of ventilation of 175 cfm is insufficient to remove the heat and moisture from the tank when the outside temperature is of the order of 90° and higher and the relative humidity above 50%. If the operation of the buttoned-up tank is prolonged the crew will suffer serious deterioration and collapse.

b. At outside temperatures between 80° and 90° F the deterioration in the tank atmosphere with prolonged buttoned-up operation, the crew will experience definite fatigue and loss of efficiency.

c. At outside temperatures up to 80° F the tank atmosphere will be acceptable from the standpoint of crew efficiency and fatigue.

d. These findings are of considerable importance in connection with the design and operation of so-called gas-protected tanks since the installation crew-cooling equipment would greatly complicate the problem. The need for such equipment depends upon two conditions: (1) climate in the combat area and (2) the conditions under which the tank must operate, that is to say, the length of time it must be driven completely buttoned-up. The latter depends upon the anticipated nature of attack by chemical agents. If, for example, the principal advantage of gas protection of the entire tank is to guard against ambush or other unexpected attacks then the tank must be prepared for attack at all times while in a combat area where the use of gas is expected. If, at the same time, moderately high temperatures are encountered there will be a need for crew cooling. These considerations must be kept in mind in the further study and development of gas protection by means of positive-pressure ventilation through a gas canister.

* A different crew of higher average body weight were employed in this test.

TABLE 1

Operating Schedule During "Standard Tank Day"

Time*	Legend of Oper. Schedule In Figs. 1 to 5	Operation
0900 to 1000		Driving over highway to range, hatches open.
1000 to 1030		Tank stationary, hatches open, crew in tank. Fan operating in gas-proof tank; engine idling in standard tank.
1030 to 1130		Cross-country driving, tank buttoned-up
1130 to 1230		Tank stationary, hatches open, engine dead, crew outside.
1230 to 1300		Cross-country driving, hatches open.
1300 to 1430		Cross-country driving, tank buttoned-up.
1430 to 1500		Tank stationary, hatches open, engine dead.
1500 to 1600		Cross-country driving, hatches open.
1600 to 1630		Driving over highway to motor park, hatches open.

* Schedule followed approximately. Time varied slightly in several tests.

TABLE 2

Location and Schedule
of
Temperature Measurements in Tank

1. Surface Temperatures (Contact thermocouple readings at beginning and end of every halting period)

   a. Bow: on front slope midway between two seats.
   b. Turret: roof over gun and on rear wall.
   c. Transmission: front, next to final drive housing.

2. Air Temperatures (Readings every one-half hour)

   a. Bow: four locations - driver's left at chest height; asst. driver's right at chest height; over transmission, midway to roof (shielded)*; to rear of and above transmission next to turret basket.
   b. Turret: four locations - at chest height at each crew position (gunner, commander, loader); center of turret directly under gun.

3. Moisture content (wet bulb temperature readings every one-half hour)

   a. Bow: to rear of an above transmission next to turret basket.
   b. Turret: center, directly under gun.

* Always higher than other bow temperatures. Not included in obtaining average bow temperature.

TABLE 3

Rise in Moisture Content
of
Tank Air in Experimental and Standard M4A3 Tanks

Time	Moisture Content - Grains Per Lb. Dry Air									
	Experimental Tank					Standard Tank				
	Outside	Bow	Percent Increase	Turret	Percent Increase	Outside	Bow	Percent Increase	Turret	Percent Increase
0830	---	---	---	---	---	129	134	4	135	5
0900	118	132	12	132	12	---	---	---	---	---
0930	---	---	---	---	---	124	134	8	144	16
1000	119	143	20	139	17	119	132	11	134	13
1030	121	150	24	141	17	119	125	5	126	6
1130*	128	214	67	202	57	112	159	42	131	17
1230	120	152	27	154	28	110	140	27	135	23
1300	115	173	50	156	35	111	115	8	131	18
1330	112	197	76	200	79	110	143	30	133	21
1400	108	215	99	204	89	118	151	28	140	19
1430*	105	230	119	218	108	112	145	29	147	31
1500	106	153	44	169	60	108	133	23	136	26
1530	106	146	38	155	46	103	127	23	129	25
1600	105	170	62	155	47	103	135	31	142	38
1630	105	137	30	140	33	---	---	---	---	---

* End of period of buttoned-up driving.

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FIG. 1

TEMPERATURES IN STANDARD M4A3 TANK

MODERATELY HOT DAY

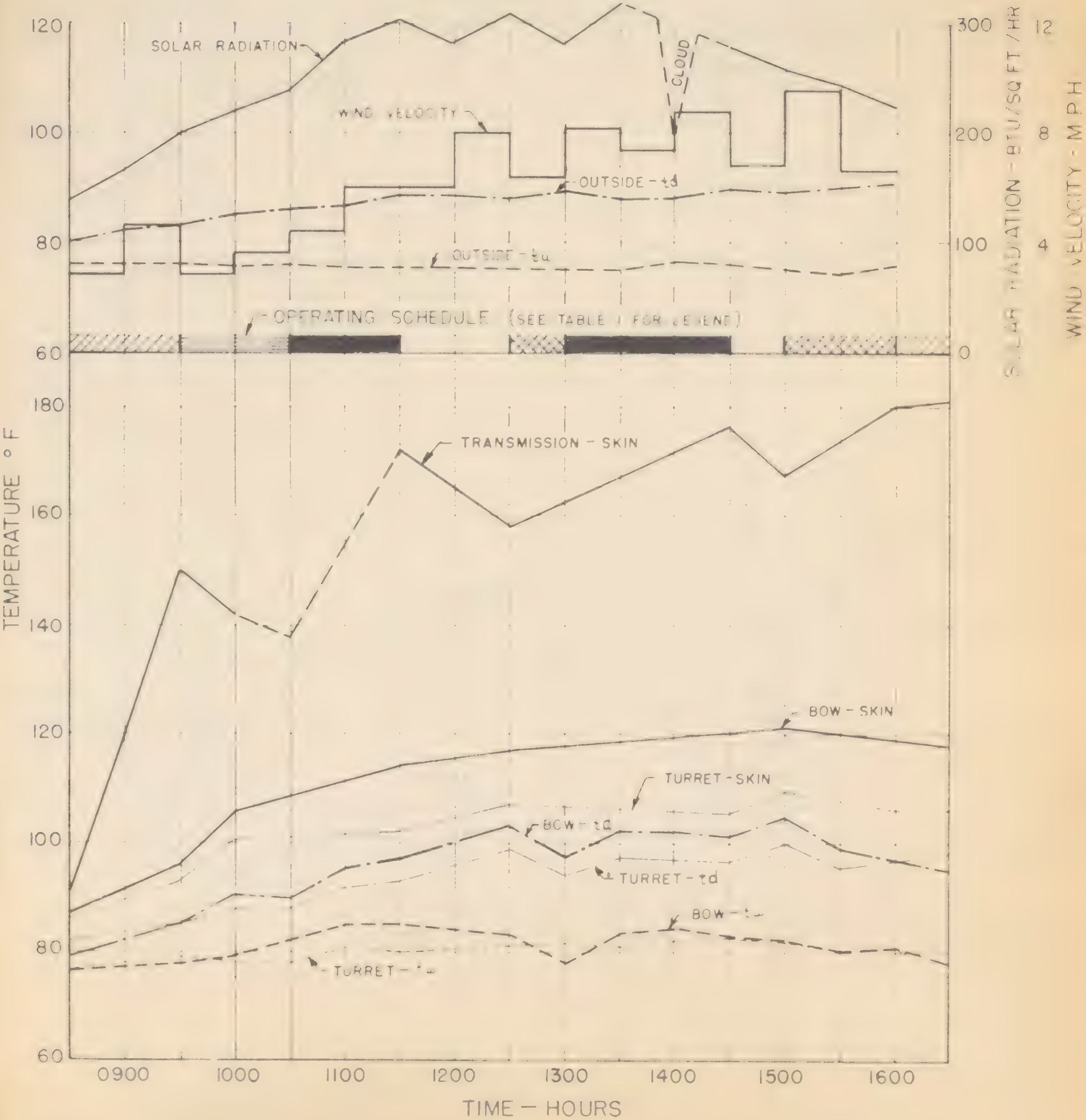


FIG. 1

FIG. 2

TEMPERATURES IN EXPERIMENTAL M4A3 TANK (175 CFM)

MODERATELY HOT DAY

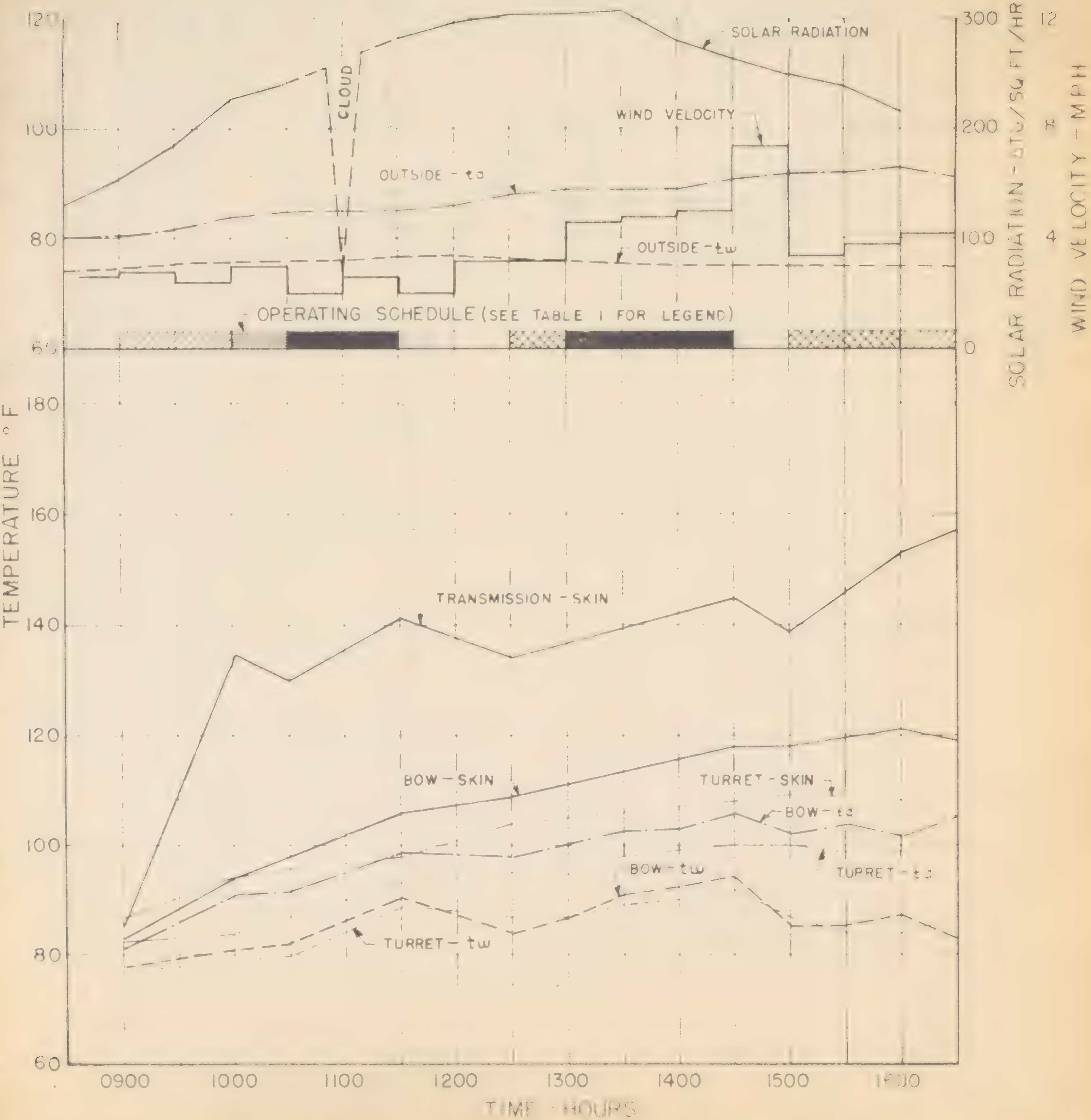


FIG. 2

FIG. 3

TEMPERATURES IN EXPERIMENTAL M4A3 TANK (175 CFM)

AVERAGE WARM DAY

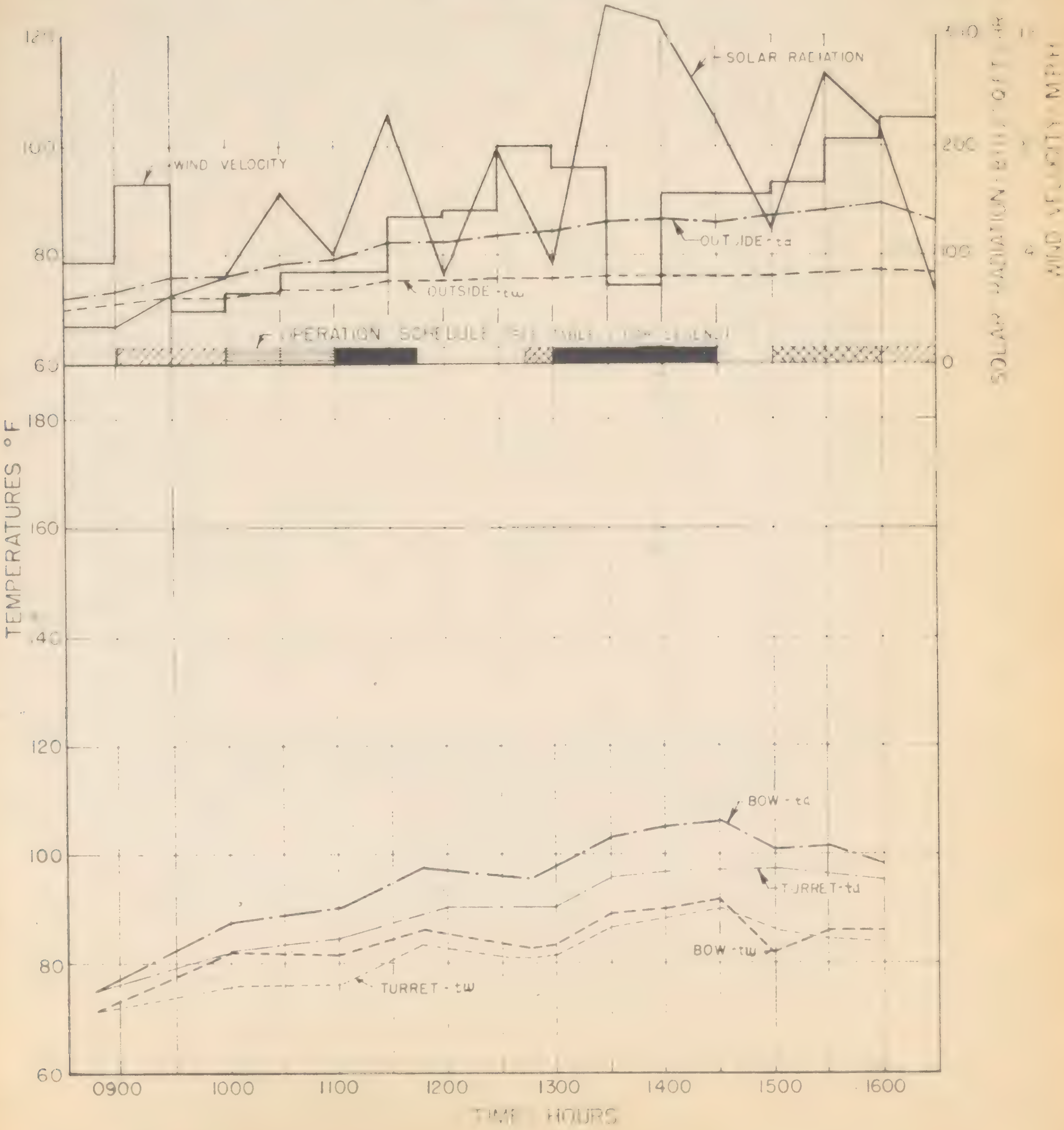


FIG 3

FIG. 4

TEMPERATURES IN EXPERIMENTAL M4A3 TANK (175 CFM)

COOL DAY

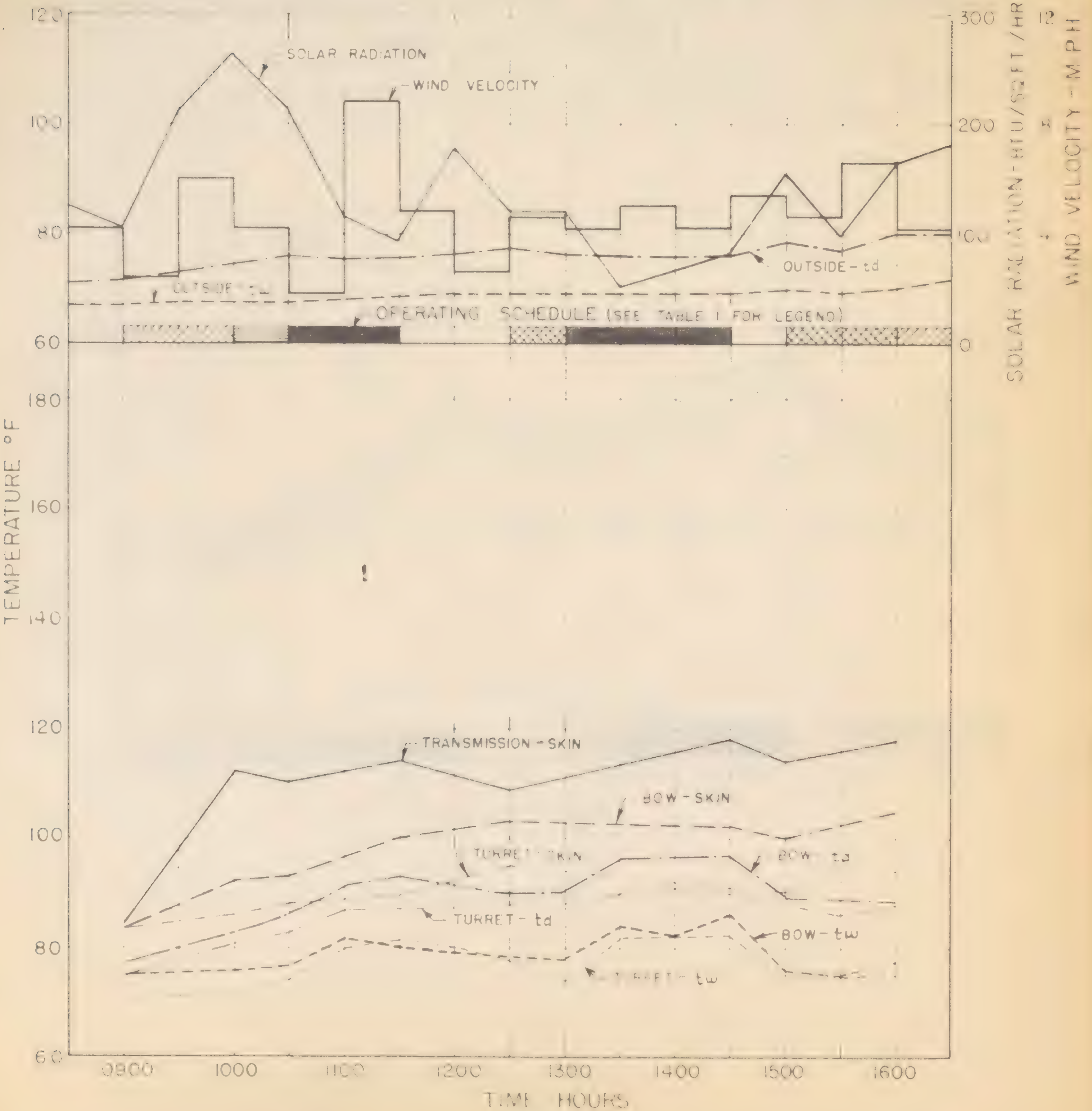


FIG. 4

FIG. 5

EFFECTIVE TEMPERATURES IN TURRET AND BOW OF EXPERIMENTAL M4A3 TANK (175 CFM)

AS COMPARED WITH STANDARD M4A3 TANK, SHOWING EFFECT OF LIMITED VENTILATION. MODERATELY HOT DAY WITH CONTINUOUS SUNSHINE.

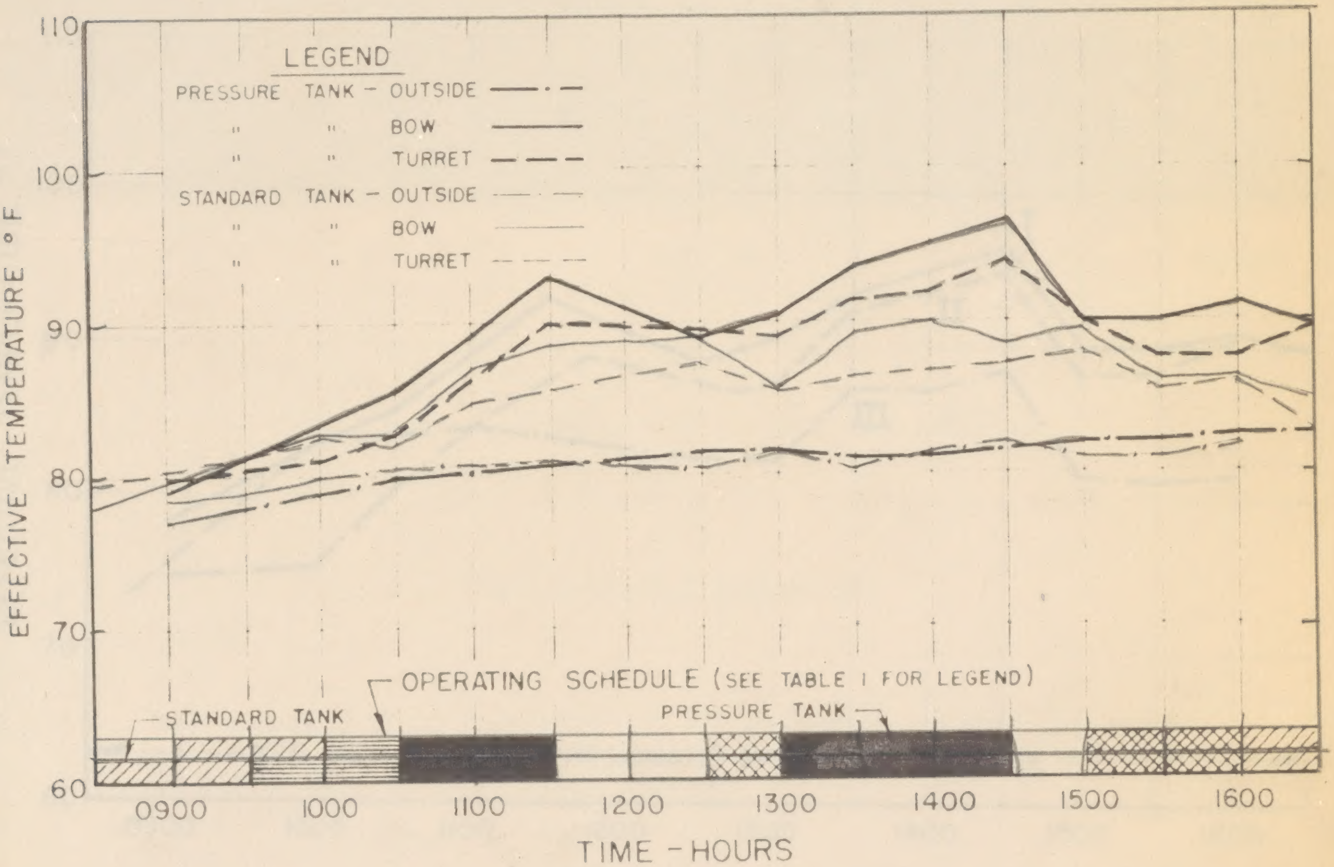
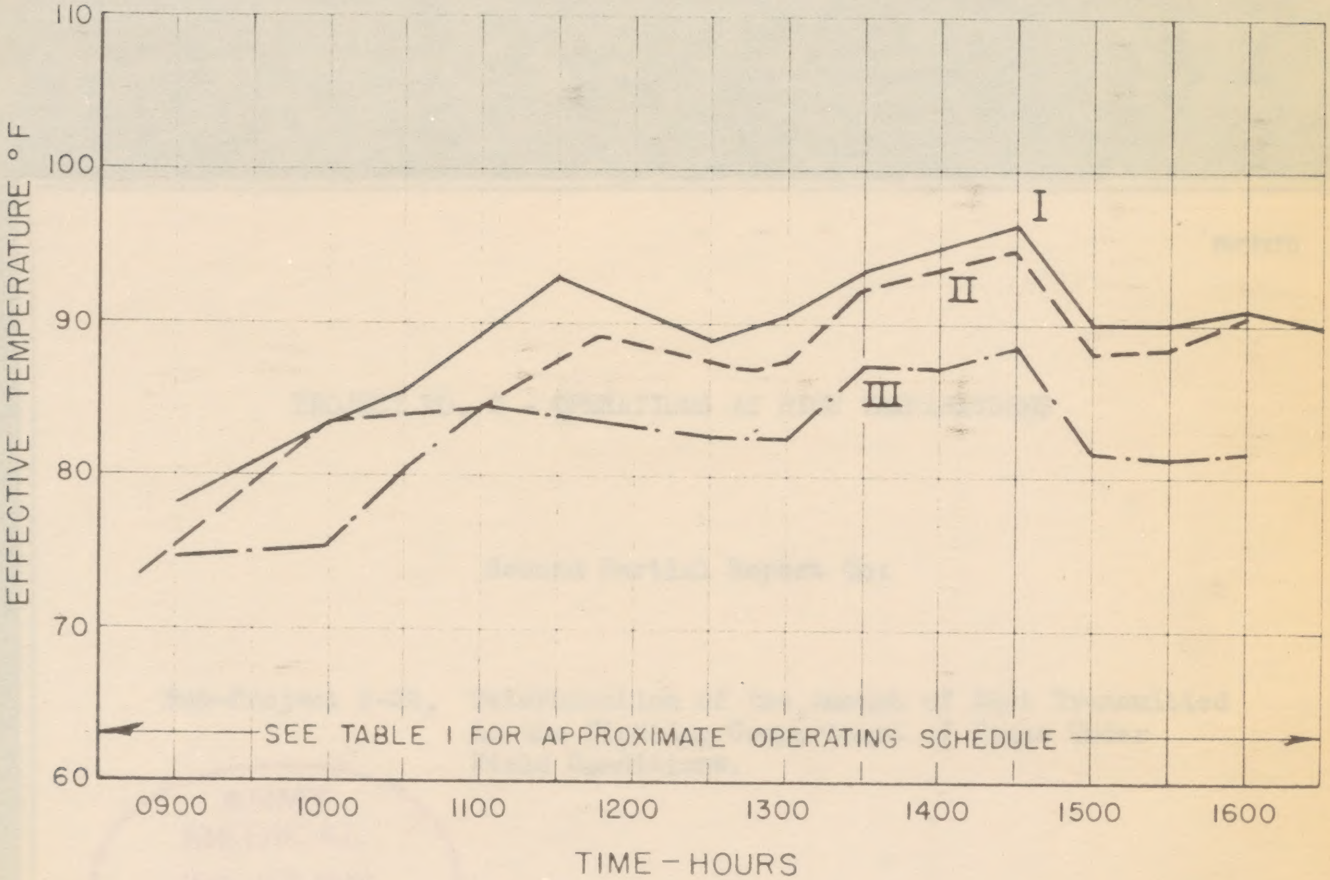


FIG. 5

FIG. 6

EFFECTIVE TEMPERATURES IN BOW OF EXPERIMENTAL M4A3 TANK
(175 CFM)

ON COOL, WARM AND MODERATELY HOT DAYS



AVERAGE CLIMATIC CONDITIONS

TEST	td	tw	WIND VELOCITY	SOLAR RAD.
I	87.0	75.5	3.6	230
II	81.5	74.0	5.4	145
III	75.5	68.6	4.5	130

FIG. 6